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Type II Solar Radio Events Observed in the Interplanetary Medium: Part I - General Characteristics

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Abstract

Twelve type II solar radio events have been observed in the 2 MHz to 30 kHz frequency range by the radio astronomy experiment on the ISEE-3 satellite over the period from September 1978 to December 1979. These data provide the most comprehensive sample of type II radio bursts observed at kilometer wavelengths. Dynamic spectra of a number of events are presented. Where possible, the 12 events have been associated with an initiating flare, ground-based radio data, the passage of a shock at the spacecraft and the sudden commencement of a geomagnetic storm. The general characteristics of kilometric type II bursts are discussed.

1. Introduction

Type II (or slow drift) solar radio bursts have been investigated in the meter and decameter wavelength range from ground-based observations over the past three solar cycles. It was only during the last solar maximum that type II events were observed at hectometer and kilometer wavelengths, using space-borne equipment. Two such events were reported (Malitson et al. 1973a, 1973b, 1976). More recently, Boischot et al (1980) have reported the observations of kilometer wavelength type II events with the radio experiment on the Voyager spacecraft. The detection of type II events is difficult over all frequency ranges because of their low

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occurrence rate compared to that of type III bursts. This point will be appreciated when dynamic spectra are presented later in this paper. In the case of the type II observations by Malitson et al., the observing instrument was aboard the earth orbiting satellite IMP-6 which, for a good part of its orbit, was also subjected to intense radio emissions of terrestrial origin (Kaiser & Stone, 1975).

There exists little doubt that both type II radio bursts and the ensuing sudden commencement geomagnetic storms detected at the earth, result from the passage of a collisionless shock front through the solar corona and interplanetary medium, at velocities of the order of 1000 km s^{-1}. Although no generally accepted theory exists concerning the mechanism by which the initiating shock front generates type II radiation, it is accepted that the emission process occurs at the local plasma frequency and its harmonic. Reviews of the subject may be found in Kundu (1965) and in Wild and Smerd (1972).

Ground-based observations of type II bursts cover the frequency range from approximately 600 MHz to 10 MHz, which, for an undisturbed corona, corresponds to a height range of about 1-5 solar radii (R_o) from the center of the sun. Space-borne observations are at frequencies corresponding to heights ranging from 5 R_o (10 MHz) out to about 1 AU ($\sim$ 30 kHz). Hopefully then, the study of type II events at kilometer wavelengths will provide a more comprehensive picture of the evolution of shock waves over a large height range. It will also be possible to compare the characteristics of the type II emission in the vicinity of the spacecraft with in situ measurements of the shock itself. This comparison, currently underway, should lead to a more definitive picture of the physical conditions required for radio emission.

In this paper we discuss type II bursts observed during the period from September 1978 through December 1979. In the following section the salient features of the experiment on ISEE-3 are discussed. A description of the dynamic spectra format is then covered. The observations section includes the presentation and discussion of dynamic spectra of two candidate type II bursts. Also included are tables showing some of the

parameters of the 12 events.

2. Observations

2.1 The ISEE-3 Experiment

ISEE-3 was launched on August 12, 1978 and is now in a "halo" orbit about the libration point situated approximately 240 earth radii upstream between the earth and the sun. This orbit is excellent for solar radio observations. The effects of plasma interaction with the antennas are negligable except at the lower end of the observing range. The spacecraft is situated in a region where terrestrial kilometric radiation is minimal (Kaiser and Alexander, 1977) and where the sun is continuously observable.

The experiment, a joint effort of the space research group of the Paris Observatory and NASA Goddard Space Flight Center, consists of two dipole antennas, one in the spacecraft spin plane designated S (90m length tip to tip) and one along the spin axis designated Z (15m tip to tip). Each of these antennas drive two radiometers, one with a 10 kHz bandwidth and one with a 3 kHz bandwidth. The receivers provide a measure of the intensity of the received radiation at 24 frequencies in the range from 2 MHz to 30 kHz with a dynamic range of 70 dB. This frequency range, for an undisturbed solar wind, corresponds to radio emission in the height range from about 10R☉ to 1 AU from the sun.

The combination of the two dipole antennas is used to synthesize a spinning "tilted" (with respect to the spin axis) dipole from which the source azimuth and elevation angles may be determined. The spin plane (S) antenna rotates with the spacecraft and the phase of the spin modulation impressed on the received solar radio burst by the rotating dipole, yields the direction of emission as projected on the spin plane at each of the 24 observing frequencies. Details of the technique for determining this information as well as source angular size have been presented by Fainberg (1979). For a more detailed description of the receiver, the reader is directed to a description by Knoll et al., (1978).

2.2 The ISEE-3 Data

The dynamic spectra presented in this pape' are generated from 23 of the 24 discrete observing frequencies; the 1000 kHz channel occurs for both the 3 and 10 kHz bandwidths. Each time sequence is composed of 108-second averages. The experiment stepping sequence is not a linear sweep in frequency as a function of time. This was done in order to take equal numbers of samples (for type III events) per burst duration at each observing frequency. However, since the burst duration increases with decreasing frequency, it is then necessary to sample the higher frequencies at a faster rate than the lower frequencies. For example during 36 frequency steps of a normal data format, the highest frequency is sampled 12 times while the lowest frequency is sampled only once.

Table I shows the center frequencies of the 24 channels and their bandwidths.

Figure 1 shows dynamic spectra obtained from the S dipole for the period from 1200 U.T. on Aug. 18, 1979 to 1200 U.T. on Aug. 20, 1979. The spectra are shown in four twelve-hour panels in time sequence. The ordinate frequency scale is actually composed of the 23 discrete frequencies listed in Table 1.

Frequency increases from bottom to top to be in accordance with the ground-based solar radio astronomy convention. Frequencies of 100 and 1000 kHz are marked for reference. However, other frequencies listed in table 1 can be identified by the discrete nature of the dynamic spectra format. Each time count represents the 108 s averages. The grey scale is a measure of burst intensity.

An intense type III burst occurs in the observing range at approximately 1420 U.T on 18 Aug. The type III burst drifts from the highest to lowest extremes of the band in less than one hour. At approximately 1700 U.T. the type II burst first appears at the high end of the band ($\sim$ 1000 kHz). Seven hours later at 2400 U.T. (end of top panel) it has drifted down to 160 kHz. Note that during this same period of

time, an additional noise band is observed. This noise band is seen near the beginning of the top panel ($\sim$1450 U.T.) (lowest frequencies) but is more apparent after the type III burst has damped out, when the noise band moves upwards in frequency until at 2400 U.T. it is centered in the 56-60 kHz channel. This noise band is part of the low frequency (L.F.) continuum reported by Hoang et al., (1980), which results from the direct coupling of the ISEE-3 antennas to the surrounding plasma. The low frequency cut-off occurs when the lowest observing frequencies fall below the local plasma frequency. In the second panel of figure 1 the type II burst and the band from the L.F. continuum almost coalesce. This illustrates one of the complications in studying type II bursts at very low frequencies.

After 0600 U.T. (Aug. 19) the L.F. noise band begins to move to lower frequencies although there is a sudden increase in the low frequency cut-off at 0740 and the ambient plasma frequency remains high for about 1 hr. At 1400 U.T. the type II burst is centered on 94 kHz and begins to disappear as a continuous entity. After this time there are several bursts of emission which are probably sporadic reappearances of the type II emission. However, on many occasions isolated sporadic emissions such as these occur and at this time we have reached no conclusion as to their origin.

At about 0600 U.T. on Aug. 20 there is a sharp increase in the L.F. continuum visible at all but the highest frequencies. This is evidence of a shock passing the spacecraft (see Hoang et. al. 1980) and is undoubtedly the shock which produced the type II radio emission. This same shock was responsible for a sudden commencement recorded from the ground at about 0700 U.T. Notice that after the passage of the shock the local plasma frequency is above the lowest observing frequency (30 kHz).

Thus figure 1 shows a hectometric type II event and illustrates the features which were looked for when selecting other events of this kind. The data were searched for slow drift features lasting for several hours possibly preceded by a large group of intense type III bursts, and possibly succeeded by the passage of a shock.

Another type II event is illustrated in figure 2. The type II emission is first observed at approximately 1100 U.T. 23 Sept. 1978 in the 513 kHz channel just after the large type III at 1000 U.T. There are isolated intensifications of this event lasting on the order of an hour, for example in the 290 kHz channel at 1500 U.T. and in the 150-188 kHz channels at 1900 U.T. These comparatively short duration intensifications are superimposed on a diffuse broadband radiation background which seems to prevail for the entire duration of the event. The intensity of the background varies, but can be seen most clearly in the second and third panels of the figure. There is some indication that this background component is composed of two bands.

In figure 3 we show an example of a drifting feature for which no corroborative ground-based data exists to support the arguement that this is a conventional type II event. It is possible that the initiating flare was situated behind the limb and that the event became visible only when the shock front expanded or was refracted sufficiently so that its radio emission could be observed by ISEE-3.

The event is first observed at about 2230 U.T. on 20 November at a frequency of approximately 290 kHz. The spectral feature, which is intense and comparatively narrow banded (see other examples), has drifted down to 123-145 kHz by 0430 U.T. on 21 Nov. at which time its dynamic spectrum is obscured by a large type III burst and sporadic terrestrial kilometric radiation (TKR). Although less intense, the drifting feature is quite clearly seen after the cessation of the TKR until obscuration by a group of type III bursts at about 1700 U.T. on 21 Nov. At this time the feature has reached a frequency in the range 66-72 kHz. Some indication of the feature persists after the group of type IIIs, but its intensity is decreased and eventually is not recognized above the background.

In addition to being more narrow banded than the 12 events thought to be type II bursts, this 20-22 Nov. event drifts more rapidly through the observing frequency range.

In summary we have shown examples of kilometric wavelength type II

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bursts which illustrate that they are composed of a diffuse drifting background and sporadic intensifications lasting of the order of an hour, not always "on" simultaneously.

In general, it is clear that there are many other phenomena occurring, including TKR, individual type III's, storms of type III's and L.F. plasma noise. These of course complicate the analysis of the less pronounced type II bursts. Additionally there are many features lasting on the order of an hour which have some characteristics similar to the type II's but whose origin is not known at present.

2.3 The Type II Events

In the period September 1978 to December 1979, 12 type II events have been identified. These have been grouped into two categories. In category 1 we have identified, with a single exception, the initiating flare. The exception results from the absence of a flare patrol. For each of the 8 events a sudden commencement was reported and for all but one event (flare E90°) metric radio emission was reported. For all events the passage of a shock was detected by our experiment, although for one event the exact time of passage could not be determined because of a data gap.

In category 2 there are 4 events. These events have been placed in a separate group because it is uncertain whether the shocks responsible for the radio emission were detected by our experiment. For the category 1 events the longest interval between the flare and the shock passage at ISEE-3 was about 50 hours and for all but one event the radio emission could be seen in the dynamic spectra up to the shock passage. The remaining event was difficult to detect because it occurred during a period of many type III bursts. For category 2 events no shocks were recorded within 60 hours of the flare. For three of the events shocks were detected after 65 hours but no radio emission was observed in the 24 hours preceeding the shock passage. Only two of these shocks produced sudden commencements.

Two explanations for the difference between category 2 and category 1 events are as follows;

1. The category 2 shocks moved much slower than the category 1 shocks, and also could not generate radio emission at low frequencies.

2. The shock fronts never intercepted the spacecraft or the earth, and the detected shocks were not related to the radio emission.

Table II lists the relevant information about the 12 events. The data were obtained from Solar-Geophysical Data-prompt reports. The average speeds are derived from the time interval between the flare and the sudden commencement.

No flare was reported at the time of start of the event on March 09, 1979. The start time was derived from the timing of the group of type III's seen with our experiment which agreed with the start of the ground-based event. We believe that the flare occurred behind the east limb in McMath region 15877. This region was active in the ensueing days. Our experiment gives a direction in the eastern hemisphere.

Finally, as mentioned previously, there are numerous drifting and non-drifting features in the data whose origin is unknown. Most of these are short-lived (~ 30 mins.) and drift very slowly, if at all. In the time period August 1978 to December 1979, there are two features that last over a day and have drift rates comparible with observed shock velocities. These could perhaps belong to a category 3. These have no ground-based counterpart, no shock is detected and no sudden commencement is reported. The dates and times for these events are listed in table III.

3. Discussion

Type II radio bursts result from the passage of a shock wave through the corona. Most type II bursts are associated with flares (Kundu, 1965), thus it is believed that the shocks which produce radio emission result from flare explosions. However the presence of a shock wave generated by a solar flare is not a sufficient condition for the production of type II radio emission. Some shocks, as observed directly in the interplanetary

medium, do not appear to be associated with a type II radio burst, and some type II bursts do not seem to be associated with a flare. The flares associated with type II bursts are usually of importance 1 or greater. However, not all large flares (importance 2 or greater) produce type II bursts, although the probability of a flare producing a type II burst increases with the importance of the flare (Kundu, 1965). The likelihood of being able to associate a type II burst with a large flare is greatly increased if the type II burst is accompanied by type IV emission. The relationship between flares, radio bursts and interplanetary shocks has been discussed by Hundhausen (1972), who finds that the detection of an interplanetary shock is most likely when a flare produces both type II and type IV radio bursts. Hundhausen calls this a II-IV radio burst pair.

On the basis of the preceding discussion it would seem that the most likely time to detect a kilometric type II burst is after a ground-based observation of a II-IV burst pair. Thus the ISEE-3 records were examined at times of reported II-IV burst pairs in the period September 1978 to December 1979. It should be noted that this examination of the ISEE-3 data was independent of the search for slow drift features as described in a previous section. No additional potential type II bursts were found. However for the 25 II-IV burst pairs reported for which flare data and ISEE-3 data were available, all but 2 of the flares produced a group of kilometric type III bursts. These were usually intense. Thus flares which produce radio emitting shocks also produce a group of type III bursts observable at kilometric wavelengths. From this we infer that if a kilometric type II burst is observed it will probably be preceded by a group of intense type III bursts. Since type III bursts have a rapid drift they occur shortly after the flare, even at kilometric wavelengths. Thus an important result is obtained viz. that the time of the initiating flare for a kilometric type II burst can be determined. One of the problems with interplanetary shock observations has been the difficulty in relating a shock to a particular flare. It is because of the presence of type III bursts before the kilometric type II bursts that we are confident of the flare associations listed in table II.
Notice in these tables that not all the kilometric type II bursts are associated with a ground-based observation of a II-IV burst pair, although

all but one event is associated with some activity (i.e. type II burst and/or type IV emission). Of the 12 events, 6 are preceded by a II-IV burst pair. Of the other 6 events, 3 were preceded by a type II event and 2 by type IV emission. The remaining event probably originates from a flare on the eastern limb and some geometrical effect may explain the absence of any preceding radio activity at ground-based wavelengths.

For category 1 events the presence of the shock passing the spacecraft is detected and in each case a sudden commencement was recorded at earth about half an hour later. In fact, the time interval between the passage of the shock past the spacecraft and the sudden commencement can give some information about the orientation of the shock normal relative to the earth-sun line. For example, the shock of the Sept, 23-25 event took only 13 minutes to travel between ISEE-3 and the earth. Since the expected interval for a shock travelling at 900 km sec^{-1} normal to the earth-sun line is $\sim$ 30 minutes, we deduce that near the earth the shock normal is inclined by $\sim 45^{\circ}$ to the earth-sun line.

The time interval between the sudden commencement and the flare can be used to obtain an average shock velocity. The average time interval for the 8 shocks was $\sim$ 48 hrs, giving a mean average velocity of $\sim$ 900 km sec^{-1}. Further information about shock velocities can be obtained from the frequency drift rates of the type II bursts at kilometric wavelengths. The relative drift rates between the different events are consistent with the calculated average velocities. The actual drift rates are of the order of 1kHz min^{-1} near 300 kHz.

The drift rate curves suggest that for some events there is a switch from emission predominantly at the fundamental, to emission predominantly at the harmonic. This phenomena is difficult to see in the dynamic spectra. However the dynamic spectra do sometimes show two bands of emission occurring at the same time, for example at 1730 U.T. on Aug. 19, 1979 in figure 1. The two bands at 1400 U.T. are probably due to band splitting.

The occurrence rate of kilometric type II bursts using the 16 months

of ISEE-3 data is about 1 per month. During this same interval there were 159 metric type II bursts reported in the Solar Geophysical Date (i.e. about 1 per 72 hrs). There were 15 decametric type II bursts reported but an unknown number may have gone undetected.

Boischot et al. (1980), using data obtained by the planetary radio astronomy experiment aboard the Voyager spacecraft, reported observations of 8 kilometric type II events during the month of April 1978. Although the month in question was one of high solar activity, the number of type II events is extraordinary compared to the statistics reported here.

The difference in occurrence rates cannot be due to experiment sensitivity because the ISEE-3 instrument is a factor or 10 to 100 times more sensitive for the detection of solar radio emissions than is the Voyager instrument.

We believe that some of the events labelled by Boischot et al. as type II bursts are in fact different phenomena and belong to the class of slow drift or no drift features lasting a few minutes to a few hours which we mentioned in an earlier section. The authors themselves noted the presence of these features in the Voyager data. It is because of the frequent occurrence of such phenomena (about one event a day) that we have used a conservative approach in selecting features as type II bursts. The criterion is that the feature must last at least 5 hours. In 5 hours a distinct frequency drift can be seen in the dynamic spectra. Note for comparison that a type III burst at 30 kHz has a duration of the order of three hours.

From our data typical drift rates for type II events are of the order of a few kilohertz min^{-1}, for frequencies between about 500 kHz and 1000 kHz. In this frequency range Boischot et al. identify features with durations less than 20 minutes as being type II events. The adjacent frequencies for the Voyager experiment are separated by more than 19 kHz so that one would need more than 10 minutes of data before it would be possible to see any drift at all.

Given the observed sporadic variations in intensity over a band of frequencies we believe it would be at best difficult to establish a systematic drift even for an event as long as one hour.

All but 3 of the type II bursts identified by Boischot et al. have durations less than an hour and we suggest that these features may belong to another class of phenomena. An occurrence of 3 kilometric type II bursts in an usually active month would be more consistent with our results and ground-based observations.

Conclusion

This paper reports the detection of type II solar radio events identified in the kilometer wavelength range from ISEE-3 observations. We have established a number of characteristics of these bursts.

1. The intensity of the bursts varies with intermittent brightenings similar to those reported for metric type II bursts.
2. The drift rates are about 1kHz min^{-1} near 300 kHz.
3. The events are assoicated with ground-based observations of type II and/or type IV emission.
4. There is some evidence for the existence of fundamental/harmonic pairs and band splitting.
5. The mean average velocity for the shocks studied is 900km sec^{-1}.
6. The occurrence rate for the time interval studied was 1 per month.
7. There may be two classes of bursts; those which can be followed all the way from a parent flare to the earth and those for which the radio emission ceases about a day before the passage of any shock. The shocks responsible for these bursts either travel slower than those responsible for cateory 1 bursts or do not pass the spacecraft.

Finally we have also reported the detection of numerous drifting and non- drifting features whose orgin is unknown.

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TABLE I

ISEE-3 OBSERVING FREQUENCIES (kHz)

10 kHz Bandwidth	3 kHz Bandwidth
41	30
50	36
60	47
72	56
94	66
123	80
160	110
233	145
360	188
513	290
1000	466
1980	1000

TABLE II

KILOMETRIC TYPE II BURSTS - CATEGORY 1

Date	Init. Flare Position & Imp.	m/dm Radio Activity	Hectometric II Duration (hrs)	Hectometric II Range (kHz)	Av. Speed (km. sec^{-1})
78/09/23	N35 W50 2B	II/IV	43	1000-47	930
78/11/10	N17 E02 2N	II/IV	44	513-50	890
78/12/11	S17 E14 2B	IV	40	513-72	750
79/02/16	N16 E59 3B	II/IV	19	360-123	840
79/04/03	S24 W11 1B	Poss.IV	37	233-80	850
79/04/23	No patrol	II/IV	25	123-72	900
79/07/04	N11 E39 2B	II/IV	43	360-41	850
79/08/18	N09 E90 1B	—	37	1000-41	1000

KILOMETRIC TYPE II BURSTS - CATEGORY 2

Date	Init. Flare Position & Imp.	m/dm Radio Activity	Hectometric II Duration (hrs)	Hectometric II Range (kHz)	Av. Speed (km. sec^{-1})
78/10/01	S14 E57 2N	II/IV	11	513-188	
79/03/01	No patrol	II	26	360-72	
79/03/09	? E90	II	11	360-188	
79/03/11	S19 W78 1B	II	16	360-94	

TABLE III

PROPERTIES OF TWO SLOW DRIFT FEATURES

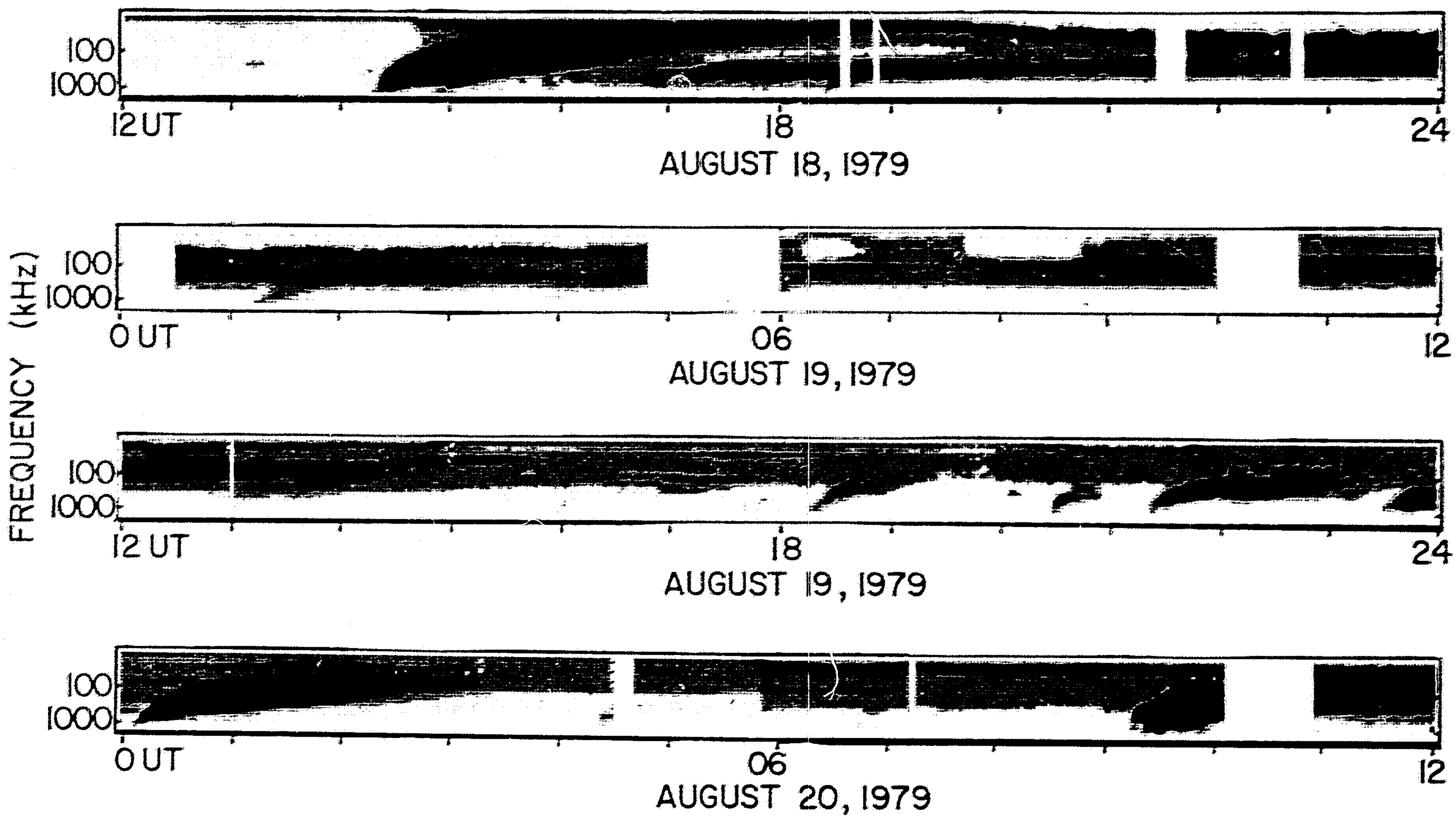
DATE	START TIME UT	DURATION HRS	RANGE kHz
78/11/20	$\sim$ 2200	22	360-50
79/03/04	$\sim$ 0500	7	233-94

FIGURE CAPTIONS

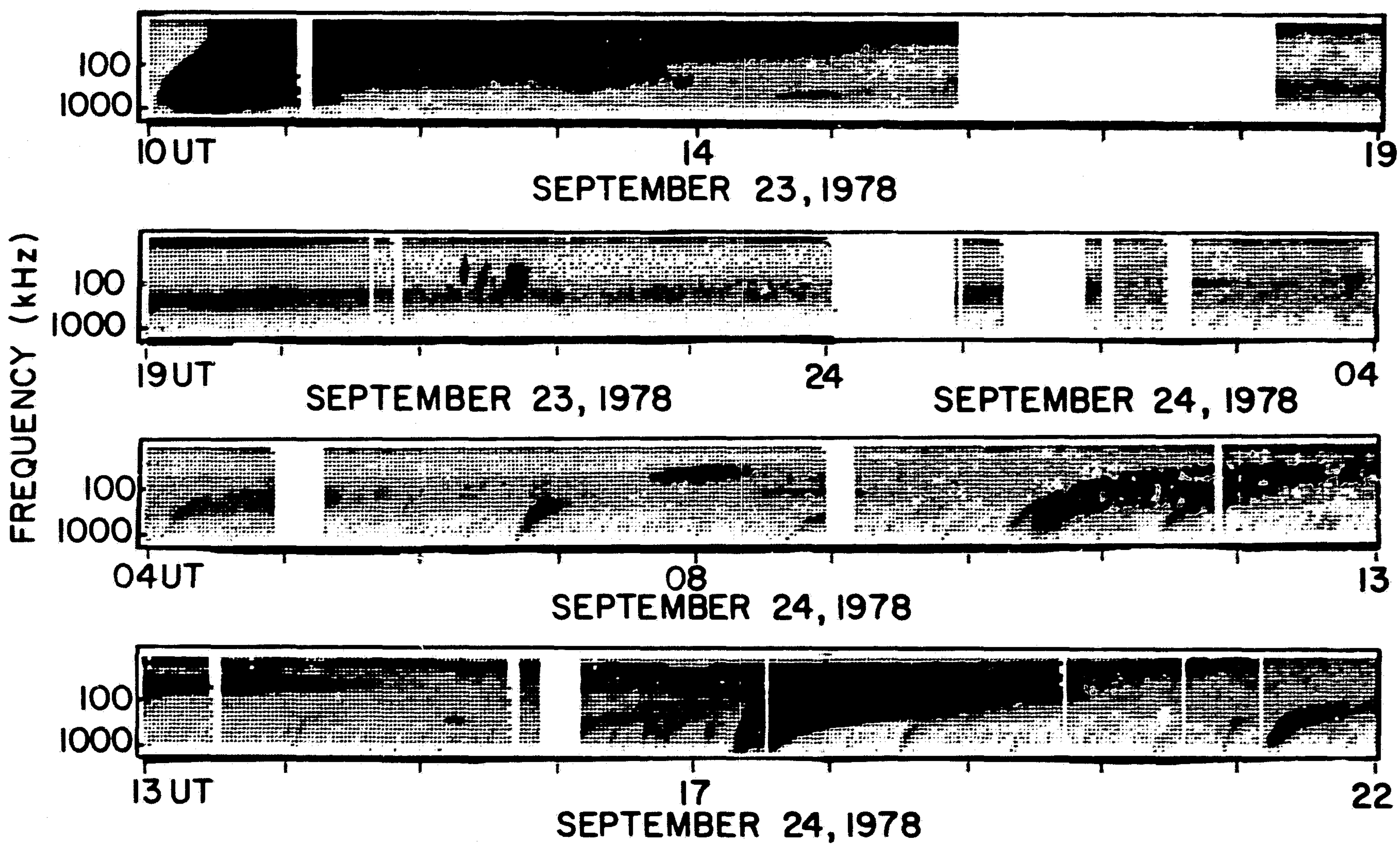
Fig. 1. ISEE-3 dynamic spectra illustrating a kilometric type II burst. The initiating flare occurred at $\sim$ 1420 on Aug. 18, 1979 and also produced a group of intense type III bursts. The shock passed the spacecraft at $\sim$ 0550 on Aug. 20. The type II radio emission is clearly visible at 1700 U.T. on Aug. 18, through to 1400 U.T. on Aug. 19.

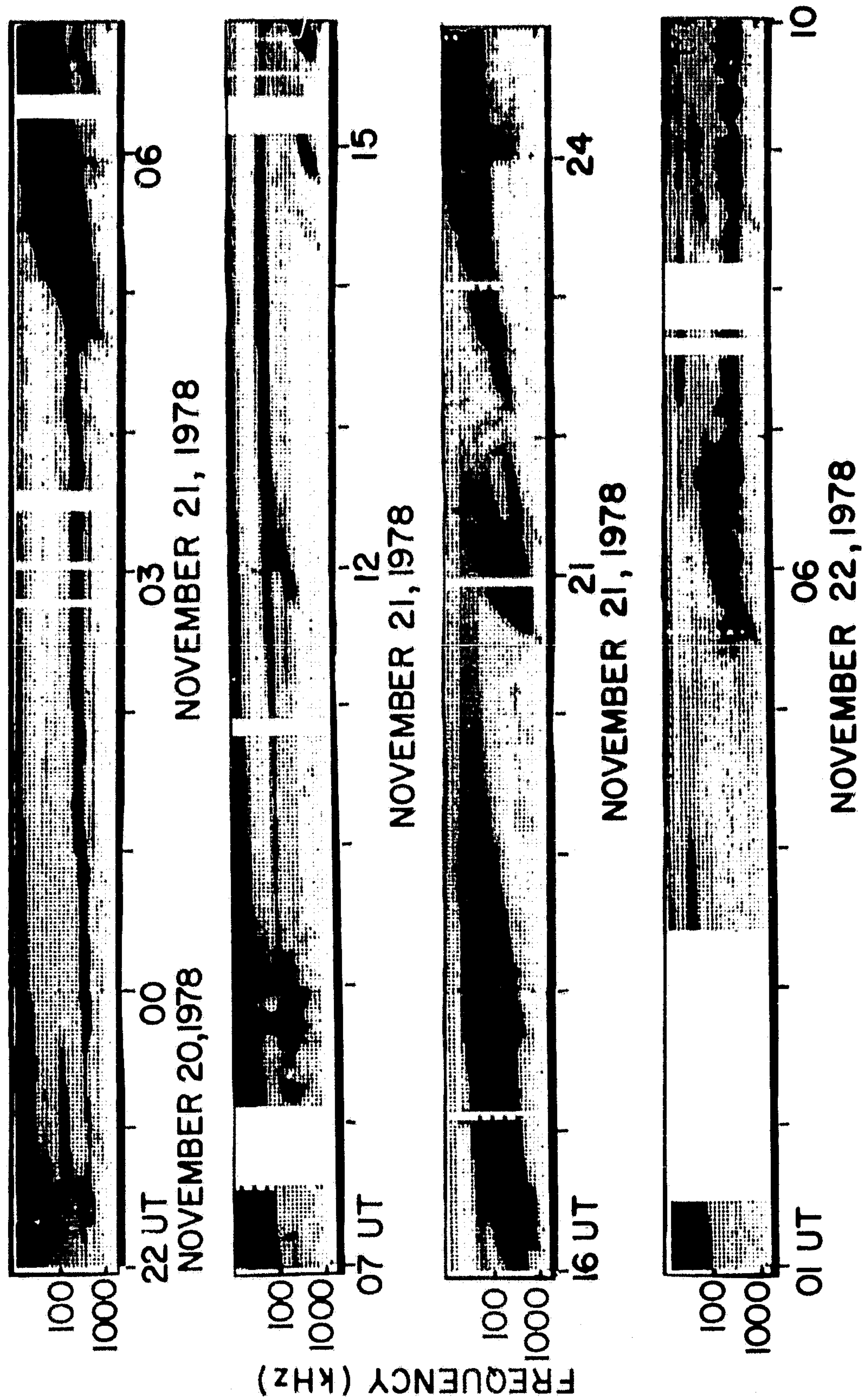
Fig. 2. Another kilometric type II burst, resulting from a flare at $\sim$ 1000 U.T. on Sept. 23, 1978. The emission is more uniform and less intense than that illustrated in fig. 1.

Fig. 3. A slow drift feature which could be a type II event from behind the limb.



FREQUENCY (kHz)
100
1000
12 UT
18
24
AUGUST 18, 1979
0 UT
06
12
AUGUST 19, 1979
12 UT
18
24
AUGUST 19, 1979
0 UT
06
12
AUGUST 20, 1979


FREQUENCY (kHz)
100
1000
10 UT
14
19
SEPTEMBER 23, 1978
19 UT
24
04
SEPTEMBER 23, 1978
SEPTEMBER 24, 1978
04 UT
08
13
SEPTEMBER 24, 1978
13 UT
17
22
SEPTEMBER 24, 1978



FREQUENCY (KHz)
100
1000
22 UT
00
03
06
NOVEMBER 20,1978
NOVEMBER 21, 1978
07 UT
12
15
NOVEMBER 21, 1978
16 UT
21
24
NOVEMBER 21, 1978
01 UT
06
10
NOVEMBER 22, 1978